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Ada-Linda Preliminary Report: Motivation, Informal Description and Examples

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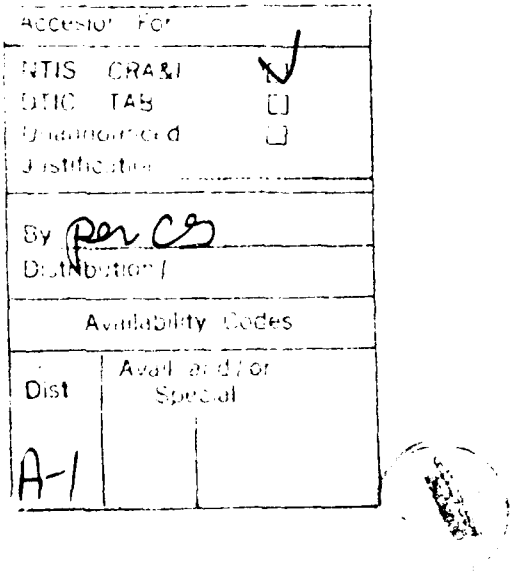

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1 Introduction

SDIO 3405 — "Strategic Defense System Software Policy" — is typical of many Defense Department policy statements in decreeing that all "mission-critical software" be implemented in Ada [SDIO 3405, p.1] The intentions behind the decree are honorable:

> A standard programming language and standard notations for specifications and designs are highly desirable to provide a common basis for understanding and to permit the development and wide usage of common tools for maintenance, evaluation and testing [*ibid.* p.3].

The software developer (duly inspired) wades into the body of the policy statement — only to discover a long section on "waiver procedures". Grounds on which the required use of Ada may be waived include "(1) performance, or (2) appropriateness of the Ada programming model" [p. 10]. Waivers in the second category may be based on the inappropriateness of Ada *interprocess communication*, *initialization* or *task scheduling*, among other things.

If the developer's plans include distributed systems or parallel applications, his enthusiasm may now be waning. *Interproccess communication* and *task scheduling* aren't minor issues. They underlie *every* attempt at parallel or distributed programming. In acknowledging Ada's deficiencies in these areas, SDIO 3405 implicitly admits that, so far as parallel and distributed programs are concerned. Standard Ada *will* not, indeed *cannot* meet its stated goal of serving as a "standard programming language."

It might be argued that (to the contrary) no programming language can do everything right, and that Ada represents a reasonable attempt at covering the bases, even if it falls short in some areas. In this report, we attempt to demonstrate that this optimistic view fails to hold water. The waiver conditions in SDIO 3405 don't overstate the case. In fact, Standard Ada is poorly suited to distributed systems and *unacceptable* for parallel applications.

1. Synchronisation in Standard Ada is inappropriate and too expensive,

2. naming is too inflexible, and

3. there is no support for safely-sharable data structures.

Furthermore, Standard Ada does not generalise to provide the support that will be wanted soon (even if it isn't now) for fine-grained asynchronous parallelism and for object-structured file systems. And so far as distributed and parallel programming in Standard Ada is concerned, insufficient power and flexibility are complemented by excessive complexity. The complexity of the tasking and interprocess communication constructs in Standard Ada is a burden to program-writers, program-readers, implementors and tools developers.

In hindsight, Standard Ada's inadequacies in these areas aren't surprising. They are a natural consequence of the crucial but frequently overlooked fact that

> the design of Ada *preceded* the decade in which parallel and distributed programming were first widely practiced.

In the absence of any substantial *experience* with parallel and distributed programming, the Ada designers made the best guesses they could. It's no discredit to them to acknowledge that, in retrospect, they often guessed wrong. But it will be to our discredit if we don't correct the mistake, before massive investment in parallel and distributed Ada software yields complex and inefficient codes at high cost — to the extent (see "waivers") that these supposed Ada applications are actually written in Ada at all.

This report gives a brief and informal description of Ada Linda. It then discusses some "Linda world examples" (parallel applications) and some "Ada world examples" (distributed system routines, of the sort the Ada designers themselves used to illustrate and explain their constructs).

2 Brief description of Ada-Linda

Ada-Linda (otherwise known as Ada Lite) is intended for implementation as a precompiler that generates standard Ada code, to be linked to the Ada Linda runtime library.

The following outline assumes familiarity with standard Ada and with Linda.

Synopsis: Ada-Linda compared with C-Linda. The Linda components of these languages are basically the same, and processes in the the two languages should be able to communicate via a common tuple space. But there

are some differences in detail. Because C has a weak type system, C-Linda makes relatively weak use of typing; Ada-Linda depends more extensively on type information.

In C-Linda, objects added to tuple space are created dynamically via **out** or **eval** statements. A C-Linda tuple *as a whole* has no explicit type. In Ada-Linda, any *single* object of *any* type may be added to tuple space via **out**; any object may be used as a template for object retrieval via **in** or **rd**. The retrieved object will be identical in type to the template object. In Ada Linda, The role of C-Linda *tuples* (i.e. of heterogeneous aggregates) is played by Ada *records* (which happen to be heterogeneous aggregates anyway). Where C-Linda adds a 3-tuple to tuple space (TS), Ada-Linda adds a 3-field record.

Formals in C-Linda are replaced by *empty fields* in Ada-Linda. Where C-Linda uses a formal in a tuple or template, Ada-Linda uses a field that is bound (via ordinary assignment statement) to the distinguished value **empty**. (Every type in Ada-Linda implicitly includes the **empty** value.) **empty** fields in templates behave in the same way as formals in C-Linda templates: after matching, they are no longer empty; they are bound to the corresponding values in the retrieved object.

C-Linda's **eval** is replaced by Ada-Linda's **ticking** prefix. Evaluation of a **ticking** expression yields a task descriptor which detonates (or in other words, starts to evaluate) when it is dumped into tuple space. Thus, both passive and live tuples are generated via **out**.

Tuple space operations in Ada-Linda. Ada Linda provides the basic operations **out**, **in** and **rd** for operating on tuple spaces, the compound operations **outin** and **inout**, and the new keywords **empty** and **ticking**.

1. **out** adds a copy of any Ada object to tuple space.

Examples:

Given the declarations

```
type RType is
 record
   name: string;
   index: integer;
   value: ValType;
 end record;

 R1, R2: RType;
```

The statements

```
R1.name := "annette";
```

```
R1.index := 25;
R1.value := V;
out R1;
```

adds a three-field record to tuple space; this operation is in essence identical to the C-Linda operation

```
out("annette", 25, V),
```

except that in Ada-Linda, all objects added to tuple space must be typed, and can be withdrawn only by templates of the same type.

The same effect can be achieved by the statement

```
out R1("annette", 25, V);
```

which initializes R1 to the aggregate value ("annette", 25, V) before out'ing it, or by

```
out R1(name => annette, index => 25, value => V).
```

(When a tuple space operation cites an aggregate-valued variable *A*, inclusion of the form

fieldname => *fieldvalue*

within parentheses after the variable's name is equivalent to executing the statement

A.fieldname := *fieldvalue*

before the tuple space operation.)

Finally, the same thing can also be accomplished by

```
out RType("annette", 25, V),
```

or by

```
out RType(name => annette, index => 25, value => V).
```

In these two cases, a new object of type RType is generated dynamically and added to tuple space (on analogy with allocation via the new statement).

The statement

```
out RType("annette", empty, V)
```

adds an object whose middle field is empty. (The role of **empty** fields in matching is discussed below.)

2. **in** withdraws an object from tuple space. (1) It may use any Ada object as a template. We refer to this object as the template-object and the object withdrawn from TS as the TS-object (2) The TS-object will have the same type as the template-object. (3) Any or all fields of a template object may have values; any or all may be **empty**. The same holds for a TS-object[1]. A *value* in the template-object must be matched either by the same value or by an **empty** field in the TS-object. A *value* in the TS-object must be matched either by the same value or by an **empty** field in the template-object. In other words,

template:		*TS-object:*
value	$\Leftrightarrow$	*value*
value	$\Leftrightarrow$	**empty**
empty	$\Leftrightarrow$	*value*
empty	$\neq$	**empty**

(4) After the **in** completes, all **empty** fields in the template-object have been filled in with the corresponding value from the TS-object. (5) If there are no matching objects in TS, **in** *blocks until one shows up.* If there are many, it makes a non-deterministic choice.

Examples. Given

```
type RType is
 record
   name: string;
   index: integer;
   value: ValType;
 end record;

 R1, R2: RType;

 out R1(name => annette, index => 25, value => V);
```

the TS-object generated by **out** may be withdrawn by

```
in R2("annette", empty, empty);
```

[1] When we say that a field *has* a value, we mean that it is *not* empty. For present purposes, we don't consider **empty** to be a value.

or equivalently by

```
in R2(name => "annette", index => empty, value => empty)
```

or by

```
R2.name := "annette";
R2.index := empty;
R2.value :=  empty;
in R2;
```

After any one of these in's,

```
R2.index = 25
```

and

```
R2.value = V.
```

The same TS-object might be withdrawn by

```
in R2(name => empty, index => empty, value => V);
```

by

```
in R2(name =>  empty, index => empty, value => empty);
```

and so on.

3. **rd** words in the same way as **in**, but without withdrawing the matched TS-object from tuple space.

4. The keyword **ticking** is used to prefix an expression. Bindings for all names in a **ticking** expression are established when the **ticking** statement is evaluated; further evaluation of the expression is postponed until the expression is added to tuple space, directly or as a top-level field of an aggregate object.

Example. The statement

```
type Worker is..;
function WorkerTask(...) ....;

out Worker(ticking WorkerTask(i));
```

is in essence equivalent to C-Linda

```
eval(WorkerTask(i));
```

It creates a live object in tuple space — i.e., a new process (a new evaluation thread or locus of execution), which evaluates the function call `WorkerTask(i)` and then turns into a single-field (passive) TS-object containing the result yielded by `WorkerTask(i)`.

Assuming the definitions above,

```
out R1(name => annette, index => ticking 3**2 + 4**2, value => V);
```

generates a live object whose middle field evaluates the given expression.

5. Ada Lite is a superset of standard Ada, but these Linda operations supercede standard Ada's **tasks**, **accept** statements and **entry** calls, **select** statements and guards. Ada Lite programs may use these Standard Ada constructs, but will never require them.

6. Topics not discussed here: *multiple tuple spaces* and *time-bounded* in and rd statements are part of Ada Lite. They will be described in the next (more formal and complete) version of this specification.

3 Linda World Examples.

Problem: a maximally-simple master-worker program. A master process creates n workers. It dumps task (or "job") assignments into tuple space; workers repeatedly withdraw a job, do it, and dump the result back into tuple space. When all results have been reported, the master adds an "All Done" task to tuple space, and the workers terminate. The Lite version is in figure 1, Standard Ada in figure 2.

(*a*) *Behavior of the Standard Ada version.* The main task creates worker tasks by using the allocator. (Dynamically allocating a new task object causes it to be activated.) The master then enters a select loop within which it accepts new-job requests or results from the workers. When all jobs have been processed, it enters a final loop in which it supplies each worker with an "AllDone" job, causing it to terminate.

(*b*) *What's wrong with the Ada version vs. the Ada Lite Version?*

First, consider job assignment. In the Lite version, workers that need jobs withdraw them directly from TS; they add results directly to TS. The Master can run ahead of the workers: it can generate job descriptions, and add them to TS, as soon as this is (logically) possible. When a worker needs a job and TS holds at least one job descriptor, the worker blocks *only* during the time

```
procedure MasterWorker(NumWorkers: integer) is

declare

 type Worker is integer;
 type JobType is [ ... ]; -- describes a single sub-task
 type ResultType is [ ... ]; -- describes a result
 i, JobCount: integer := 0;
 JobDescription: JobType;

 function WorkerTask return integer is
  declare
    Job: JobType;
    Result: ResultType;
  begin
   loop
    in Job(Empty);     -- withdraw a job
    exit when Job = AllDone;
    Result := WorkOn(Job); -- do it
    out Result;        -- dump result
   end loop;
 out Job(AllDone); -- replace "all done" token;
 return 1;
 end WorkerTask;


begin

 for i := 1 to NumWorkers loop  -- create workers
  out Worker(ticking WorkerTask());
  end loop;

 while (more jobs) loop  -- dump job descriptors
  JobDescription := Next job;
  out Job(JobDescription);
  JobsOut := JobsOut + 1;
  end loop;

 while (JobsOut > 0) loop  -- collect results
  in Result(Empty); -- collect answers;
  Do something with the Result;
  JobsOut := JobsOut - 1;
  end loop;

  out Job(AllDone);

end;
```


Figure 1: Ada Lite version

```
task body MasterWorkers is


 task type WorkerTask is

   loop
     Master.GetJob(Job);
     exit when Job = AllDone;
     Result := WorkOn(Job);
     Master.Report(Result);
   end loop;
  end WorkerTask;

task body Master is
declare
 worker: access WorkerTask;
begin
 for i := 1 to NumWorkers loop  -- create workers
  worker := new WorkerTask;
  end loop;

  while (more jobs) OR (JobsOut > 0) loop
   select
     when (more jobs) =>
      accept GetJob(J: JobType) do
        J := Next job;
      end GetJob;
      JobsOut := JobsOut + 1;
   or
     accept Report(R: Result);
     JobsOut := JobsOut - 1;
     do Something with the Result;
   end select;
  end loop;

 for i := 1 to NumWorkers loop
  accept GetJob(J: JobType) do
    J := AllDone
  end GetJob;
  end loop;

end MasterWorkers;
```

Figure 2: Standard Ada version

necessary to withdraw the descriptor from TS. The master can generate new job assignments or collect results *while* workers are withdrawing job assignments.

In the Standard Ada version, workers must rendezvous with the master in order to get job assignments. When a worker needs a job, it must block until the Master is scheduled, accepts its request and generates a job descriptor (or withdraws one from a local holding pen). Thus, even when a job-seeking worker is the *only* process to be seeking work at a given time, a job-assignment is a more complex operation in Standard Ada then in Lite. But suppose that n workers simultaneously require assignments. In Lite, all n reach into TS and withdraw assignments simultaneously; in Standard Ada, they form an n-long queue at the "GetJob" entry. The *nth* worker is blocked until the previous $n-1$ have all gotten assignments. Because the Master task must respond personally to each job request, it is a potential bottleneck.

> *Objection:* If n Lite workers attempt to withdraw objects from TS simultaneously, aren't they also forced to access TS serially, leading to the same kind of queueing delays as in Standard Ada?
>
> *Answer:* Let's assume that the Lite implementation in fact stores all job descriptors in a single TS segment, with a single lock. If this is the case, the n Lite workers are indeed serialized upon access to TS. *But:* each worker in line need only acquire a lock, withdraw the head element of a queue of tuples, and release the lock. In Ada, each worker in line needs to execute an entire rendezvous with the master task before the next worker gets its turn. In Lite, tuples can be moved asynchronously *out* of the master's address space and *into* some space that is conveniently accessible to the workers (i.e., into TS — into shared memory or system buffers, depending on the host hardware). Job descriptors are "staged", set-up for fast and convenient grabbing by the workers — *while* the workers are busy (on some previous job). Ada doesn't allow this kind of staging. Job descriptors remain stuck in the master's address space until workers claim them explicitly.

Now, consider the returning of results. In Lite, workers add result objects directly to TS; they block only during the period that is required to add a new object to TS.

In Standard Ada, workers must again rendezvous with the master task in order to return results. Even if the master is otherwise idle when a result is to be returned, the worker must block (again) until the master is scheduled and has accepted its result. But suppose that n workers attempt to return results simultaneously: again, the consequence is an n-long queue of workers awaiting rendezvous. Note that, while workers blocked awaiting rendezvous with the "GetJob" entry at least have a quasi-legitimate reason for waiting (this may

be a costly way to get a task assignment, but they can't proceed until they've gotten one somehow or other), workers who are blocked awaiting rendesvous with the "Report" entry are blocked *for no logical reason whatsoever.* They do *not* need a response from the master.

In our programming experience, this situation — processes with data objects to disseminate, with no logical need to await a response or a result — is ubiquitous. Forcing such processes to block while their data objects are "accepted" by some other process is perverse. Not only is it costly, it's conceptually inept. It hides the real nature of the transaction behing the false front of a remote procedure call. An expressive language allows the programmer to code simple operations simply, without circumlocutions.

Finally, consider the interaction between job assignment and result reporting. In Lite, there is none: one worker can be withdrawing a job assignment while another is adding a result to TS. In Standard Ada, a process with a result to report can be forced to wait *not only* while other processes report results, but *while other processes are assigned jobs* — results are accepted and jobs are assigned by a *single* master task within a *single* accept loop. Similarly, job-seeking workers may have to wait while other workers report results.

> *Objection:* couldn't Ada have used a series of two loops, the first to assign jobs and the second to collect results, as the Lite version does?
>
> *Answer:* No. As soon as a worker attempted to return a result, it would block until all jobs had been assigned and the first accept loop had terminated. This scheme makes it impossible for workers to return results until all jobs have been assigned; hence workers must build and maintain local result buffers, and return them upon completion. Sometimes this is acceptable. Other times it is pure nuisance-overhead.

A more complex master-worker program

Problem: compute the elements of a matrix each of whose elements is defined in terms of the elements directly above and to the left of it — *i.e.*, we can compute all elements along a counter-diagonal simultaneously as soon as we know the previous counter-diagonal. *Strategy:* The matrix is divided into sub-blocks. A job assignment consists of computing all sub-blocks in a given row-band. As soon as the *ith* sub-block in a band is complete, its bottom row is communicated to the process working on the band immediately below, so that it can proceed to compute its own *ith* sub-block. When a worker is finished with the j^{th} row band, it proceeds to the $j + NumWorkers^{th}$ band.

How does each worker communicate its bottom-row segment to the next? The solution is simple and immediate in Lite:

```
-- I'm working on row-band i, about to compute the j^th column
block;
-- I need a bottom row from the block above in order to proceed:
in BottomRow(row => i-1, column => j, Vector => empty);
... compute, referring to BottomRow.Vector(index) ...
... I put my own newly-computed bottom row in NewVec ...
-- Release my newly-computed bottom row segment to next worker:
out BottomRow(row => i, column => j, Vector => NewVec);
... now proceed to my j + 1st column
```

The equivalent solution — each worker communicates bottom-row information directly to the next worker — is in effect impossible in Ada. Each worker task would need to begin the computation of each block by executing an accept statement, by means of which the worker directly above would pass in a newly-computed bottom row. At the end of each block computation, it would call the corresponding entry in the worker directly beneath:

```
-- I'm working on row-band i, about to compute block j;
-- I need a bottom row from the block above in order to proceed:
accept BottomRow(Vector: VectorType);
... compute, referring to Vector(i) ...
... I put my own newly-computed bottom row in NewVec ...
-- Release my newly-computed bottom row segment to next worker:
NextWorker.BottomRow(NewVec); -- entry call
... now proceed to my j + 1st column
```

But this is unacceptable. The concluding entry call prevents this worker from proceeding until a rendezvous with the next worker has been achieved. Even if the next worker is ready and waiting at its own accept statement, the accept-mediated data transfer forces the sender to wait until the receiver has been scheduled and the data has been transferred into the receiver's address space — again, pointless overhead. Once the bottom-row has been transferred out of its own address space, the sender has nothing more to gain by waiting. In the Lite version, the sender proceeds as soon as its data has been added to TS. However, the next worker may *not* have reached its corresponding "accept" statement. It may be running behind, and may still be busy on an earlier (further-to-the-left) sub-block; or it may not yet even have *begun* computing this band. Suppose we have 5 workers and 20 row bands. When the worker computing the fifth band from the top attempts to communicate a bottom row to the worker responsible for the sixth band from the top, this next worker may still be at work on the *top* band (*i.e.* on band number 1). (Arranging things

in such a way that there are more bands than workers maximises parallelism by minimising sub-block size. Smaller sub-blocks mean shorter initial waiting periods until all workers can get started, and a shorter final shut-down period during which workers gradually drop out.)

So we try something else. Workers execute entry calls to the master in order to deposit or retrieve bottom rows; the master executes

```
loop  -- first attempt
  select
   accept PutBottomRow(i: integer, vector: VectorType) do
    Buffer(i) := vector
   end PutBottomRow
 or
  accept GetBottomRow(i: integer, out vector: VectorType) do
   vector := Buffer(i);
  end GetBottomRow
```

This version doesn't work, because a worker might call "GetBottomRow" *before* the row it needs has been deposited. Clearly we need a guarded accept. But the solution above can't be corrected by installing a guard, because the guard-condition would depend on the parameter to the entry call. That is, we would need

```
 when Available(i) =>
  accept GetBottomRow(i ... )  -- need same binding for i
```

which is not allowed. Families of entries *are* allowed, but there doesn't seem to be a way to use them here, because we can't create an array of accept statements; each family member must be specified explicitly. Not to say that there isn't a solution along these lines. We could use the technique discussed in chapter 11 of the Ada Rationale: if the GetBottomRow entry accepts a rendezvous only to discover that it can't meet the client's needs, it instructs the client (via pre-arranged protocol) to go to the end of the line, by calling the same entry again; the next time its turn comes at the head of the accept queue, it may be luckier. The ludicrous complexity of this technique makes it clearly unacceptable (as the Rationale's authors themselves seem to realise).

Which is just as well; this style of solution — the master task buffers each bottom row — is undesirable in any case, for reasons discussed in the previous example. Workers incur the overhead of rendezvous with the master; they may be forced to wait their turn at the head of the line; workers depositing rows may have to wait for workers withdrawing rows, and *vice versa*; as before, workers *depositing* rows require no response from the master task in any case, and so the overhead they incur is especially pointless. This sort of master task is a breeding-swamp for overhead and bottlenecks.

The solution in this case is to create an array of tasks. Each task executes

```
accept PutBottomRow(v1: Vectortype) do
   vector := v1;
end PutBottomRow;
accept GetBottomRow(out v2: Vectortype) do
   v2 := vector;
end GetBottomRow;
```

Note that we need $rc - c$ of these tasks, where we have r row and c column bands. That is, we need one task for *each* bottom row that is to be passed from one worker to another. (Along the final row band at the bottom, we don't need to communicate bottom-row data.) We can dispense with guards, because a bottom row must always be deposited before it is claimed.

Note that each one of these many buffers tasks is, from an algorithmic point of view, completely unnecessary. *None* of these tasks does any computing or speeds up the computation in any way. *For all its complexity, it's difficult to* regard this as better than a marginally acceptable solution, if that.

The general point. Processes in a parallel application often need to exchange data. Lite provides an easy and convenient way to do this; the data is simply added to TS, labelled in some natural way. In Ada, there is no shared object memory; data must be buffered by tasks explicitly provided for the purpose. Designing the appropriate buffer tasks adds to the complexity of the programming job. It may also confront the programmer with an unpleasant choice: either he provides one or some minimal number of tasks, making each one a potential performance chokepoint and in some cases causing complicated synchronization problems, or he provides lots of tasks, creating a complex (a *pointlessly* complex, in algorithmic terms) runtime program structure.

Dynamic process creation, result-parallelism and fine-grain parallelism.

[*In the full report.*]

4 Ada World Example.

Problem. Provide a bounded-buffer service: clients deposit and withdraw data objects; consumers block if the buffer is empty, producers if it is full.

Figure 3 gives a standard Ada solution. Lite's version of a solution in this style is given in figures 4 and 5. This Lite program is unidiomatic; we discuss a

```
task body buffering is
  buffer: array(1..n) of elem;
  i,j: integer := 1;
  count: integer := 0;
begin
  loop
     select
       when count > 0 =>
        accept read(x:out elem) do
          x := buffer(j);
        end;
        j := j mode n+1; count := count-1;
     or
      when count < n =>
        accept write(x: in elem) do
          buffer(i) := j
        end;
      i := i mode n+1; count  := count+1;
     end select;
   end loop;
end buffering
```

Figure 3: Standard Ada version

better approach below. Standard Ada's version of this solution is more concise than the Lite solution in figures 4 and 5.

Having noted this fact, the explanation is significant. In Standard Ada, communication in the remote-procedure-call style is hardwired into the language. When an application actually *needs* this style of communication, Standard Ada accomodates it neatly. When an application needs some *other* kind of communication, it's likely to be out of luck. We discussed above how complicated it can be to achieve Lite-style asynchronous communication via Standard Ada's entry calls and tasks.

In Lite, the situation is reversed. Remote procedure call is *not* built in; if you need it, you must build it yourself, by using an out to send a request followed by an in to receive the result (see figure 5). (In the bounded buffer example, consumers who have invoked the buffer service need to block until a result can be returned.) As the Lite solution shows, it's easy to achieve this effect in Lite — far easier than it was to achieve a Lite-style solution in Standard Ada.

```
type buffReq(req: reqtype) is
  record
    val: Elem;
  end record;

type EmptyBuffAvail is 0;
type FullBuffAvail is 0;

procedure BufferTask;
Req: buffReq := (Empty, Empty);
begin
  for i:= 1 to BuffSize loop
    out EmptyBuffAvail;
  end loop;
  begin
   loop
     in Req
       case Req.reqType is
        when PUT =>
          Buffer(j) := Req.val;
          j := j mod N + 1;
          out FullBuffAvail;
        when GET =>
          out Req(Req.val => Buffer(i));
          i := i mod N + 1;
          out EmptyBuffAvail;
        end case;
   end loop;
end BufferTask;
```

Figure 4: Task definition for the Lite version of the Ada-style solution (see next figure also).

```
procedure read(X: out Elem) is
 Req: buffReq := (GET, 0);
  -- I assume 0 is a legitimate value for "val"; this allows me
  -- to match this TS tuple against a template whose second field
  -- is empty
 begin
  in FullBuffAvail;  -- is there a full?
  outin Req; -- equivalent to "out Req;  in Req"
  X := Req.val;
 end read;

procedure write(X: in Elem) is
 Req: buffReq := (PUT, X)
 begin
  in EmptyBuffAvail;  -- is there an empty?
  out Req;
 end write;
```

Figure 5: The procedures used to invoke the Lite task.

The distributed solution

In Lite, though, this whole approach makes little sense. Standard Ada has no choice but to provide a task whenever shared data must be buffered. Lite allows such data to be stored directly in tuple space.

Each buffer slot in the bounded buffer is represented by a TS-object. This object's first field is an index; its second is either the buffered datum itself, or **empty** (if this slot is currently unoccupied). Two other TS-objects store the current indices of the first *unoccupied* buffer slot and the first *full* buffer respectively.

When a process needs to drop something into the buffer, it starts by consulting the index of the first unoccupied slot, and then incrementing this value. (If the value was 10, it plans to fill the buffer whose index is 10; the next producer will fill the buffer whose index is 11, and so on.) Accordingly it execute

```
  in NextFree(Empty);    -- what's the index of the next free buffer?
     NextFree:= NextFree + 1;
  out NextFree;          -- I'll take it; next guy gets the next free
buffer
```

Now it grabs the 10*th* buffer, fills it, then drops it back into TS; val is the

datum to be deposited in the buffer:

```
inout BufferElt(NextFree, val); -- grab free buffer, fill it, dump
it back
```

This compound **inout** form is shorthand for (is identical to) the sequence

```
in BufferElt(NextFree, val);
out BufferElt(NextFree, val);
```

Note that the **in** statement grabs a TS-object whose first element is the integer `NextFree` and whose second is **empty**. After this transaction, the value of the second field of the `BufferElt` record is `val`. (This **in** doesn't actually change the value of any of `BufferElt`'s fields, because none of its fields were **empty**. It merely block until the **empty** buffer for which it is waiting becomes available.)

Processes that need to withdraw an element from the buffer follow the same procedure. First, they consult and increment a `NextLoaded` index. Next, they wait for the loaded buffer to show up, by executing

```
in NewElt(NextLoaded, empty);
```

In this case, the second element of the matching TS-object must *not* be **empty** (two **empty**'s don't match). When this **in** statement completes, `NewElt`'s second field contains the datum from the buffer. Finally, a new, empty buffer is dumped at the end of the line. The end of the line will be `NumBuffs` down from the full buffer I just withdrew:

```
out BufferEltType(NextLoaded + NumBuffs, Empty);
```

There may be processes awaiting empty buffers; if so, one of them (the first to put in its request) is waiting for *this* buffer (*i.e.*, it's blocked at an **in** statement awaiting an **empty** buffer whose first element is the index value `NextLoaded` + `NumBuffs`). It grabs this buffer, fills it, and the process continues.

This solutions saves the overhead of creating and scheduling an extra task; users of the bounded buffer no longer need to rendezvous with a task in order to use the buffer; the objects in the buffer are stored in tuple space, and are therefore directly accessible to buffer users, instead of being stuck inside a buffer task's address space. So long as some slots are free and others are full, consumers and producers can access the buffer simultaneously (as they cannot in the Standard Ada-style solutions). Note that the Standard Ada-style solution gets worse as the number of buffers increases: more buffers means more tasks, or greater bottleneck-potential for a single task.

```
package body BUFFER is
declare
  type FreeIndex is integer;
  type LoadedIndex  is integer;
  type BufferEltType is
    record
     index: integer;
     content: Elem;
  end;

procedure put(in val: Elem);
declare
  NextFree: FreeIndex;
  BufferElt:  BufferEltType;
begin
  in NextFree(Empty);   -- what's the index of the next free
buffer?
     NextFree:= NextFree + 1;
  out NextFree;          -- I'll take it; next guy gets the next
free buffer
  inout Elt(NextFree, val);   -- grab next free buffer and fill
it
end put;

procedure get(out val: Elem);
declare
  NextLoaded: Loaded;
  NewElt: BufferEltType;
begin
  in NextLoaded(Empty);  -- what's the index of the next loaded
buffer?
     NextLoaded := NextLoaded + 1;
  out NextLoaded;         -- next guy takes the next loaded buffer
  in NewElt(NextLoaded, Empty);   --  grab the loaded buffer
  out BufferEltType(NextLoaded + NumBuffs, Empty);  -- empty it,
and replace it
  val := NewElt.content;
end get;

begin
  for i:= 1 to BuffSize loop
     out BufferElt(i, empty);
     end loop;

  out NextFree(1);
  out NextLoaded(1);

end BUFFER;
```


Figure 6: Ada Lite version

A more complex Ada-world example

[*In the next version.*]

5 Multiple tuple spaces

[*In the next version.*]

6 File systems

Lite includes a built-in object-structured file system. Programs can create many tuple spaces; a persistent tuple space plays the role of a file. Objects are deposited in the file via `Space.out` (`Space` is the name of some persistent tuple space), read via `Space.rd` and updated via `Space.in` followed by `Space.out`.

Who needs an object-structured file system? Returning to the bounded buffer example: suppose this buffer represents long-term rather than temporary storage. A consumer process may withdraw some element that was deposited earlier (minutes, days, years earlier) by a producer that has now terminated. We can use such a structure to coordinate (for example) data-producing and data-analysing or data-visualizing programs. While the data is being produced, all available computing resources are be devoted to producing it (or receiving it); later, other programs need to inspect this data.

The distributed bounded buffer program still works. Prefixing tuple space operations with the appropriate tuple space name is the only change required. The Standard Ada solution can't be extended in this way. Standard Ada's tasks and accept statements have nothing to do with files and file i/o.

A more complete discussion of the tuple spaces as object-structured files will be included in the next version.